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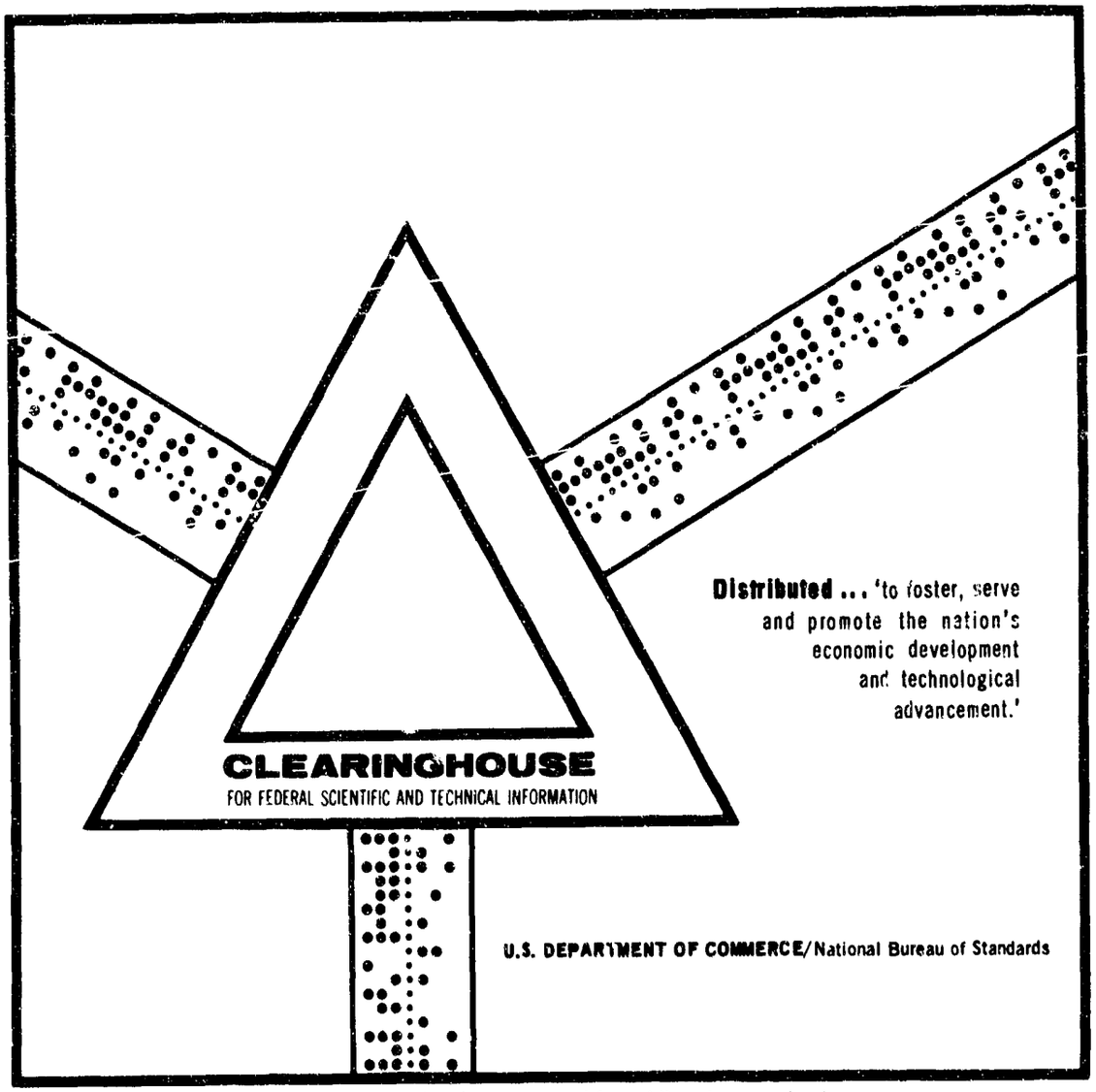

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PERFORMANCE OF MONKEYS AFTER PARTIAL BODY IRRADIATION

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FOREWORD
(Nontechnical summary)

The results of several studies have shown that, for a broad range of supralethal doses of ionizing radiation, postirradiation performance of trained monkeys has a rather well-defined pattern. Almost immediately after irradiation there is a period of transient performance decrement; within 2 hours, ability to perform effectively usually returns to a functional level. Later there is a period of permanent complete incapacitation, and death occurs shortly thereafter.

The main purpose of this research was to determine whether head shielding or trunk shielding would alter the pattern of postirradiation performance. Another purpose was to assess the relative importance of head and trunk structures in postirradiation performance decrement.

Fifteen male and fifteen female monkeys (Macaca mulatta) were trained by shock avoidance conditioning to work a visual discrimination problem. Each animal received a 4500-rad midline tissue dose of pulsed mixed gamma-neutron radiations; of each sex, five were head-shielded, five were trunk-shielded, and five were not shielded. The midline tissue dose behind the shield was less than 8 percent of the midline tissue dose to the same point without the shield in place. Postirradiation performance was evaluated.

The results indicate that, after irradiation under the conditions of this study, there is a high probability that severe early performance decrement will occur in unshielded monkeys. Either trunk shielding or head shielding will decrease the probability of early performance decrement. However, if a shielded animal does suffer

an early performance decrement, the head-shielded monkey will recover sooner than the trunk-shielded monkey.

The results also indicate that, if a monkey survives the first 2 hours postirradiation, it will recover to perform well for some time before death. Since both types of shielding decrease the probability of an early death, both will increase the chance that a shielded subject can work effectively at some time after irradiation, even though early transient incapacitation might occur.

ABSTRACT

Fifteen male and fifteen female monkeys (Macaca mulatta) were trained by shock avoidance conditioning to work a visual discrimination problem. Each animal received a 4500-rad midline tissue dose of pulsed mixed gamma-neutron radiations; of each sex, five were head-shielded, five were trunk-shielded, and five were not shielded. The midline tissue dose behind the shield was less than 8 percent of the midline tissue dose to the same point without the shield in place. Postirradiation performance was evaluated. Early performance decrement occurred after irradiation in all unshielded monkeys. Either trunk shielding or head shielding decreased the probability of performance decrement. However, among the shielded monkeys that did suffer an early decrement, the head-shielded subjects recovered sooner than the trunk-shielded subjects.

I. INTRODUCTION

The results of several studies[2-4] have shown that, for a broad range of supralethal doses of ionizing radiation, the postirradiation performance of trained monkeys has a rather well-defined pattern. Almost immediately after irradiation there is a period of transient performance decrement; within 2 hours or less, ability to perform effectively usually returns to a functional level. Later there is a period of permanent complete incapacitation, and death occurs shortly thereafter.

The main purpose of this research was to determine whether head shielding or trunk shielding would alter the pattern of postirradiation performance. Another purpose was to assess the relative importance of head and trunk structures in postirradiation performance decrement.

II. PROCEDURE

The subjects were male and female monkeys (Macaca mulatta) that weighed between 3 and 5 kg. The monkeys were trained by shock avoidance conditioning to work a visual discrimination problem. They were continuously restrained in primate chairs for about 25 days, i.e., the period required for training, exposure, and postexposure testing. Each chaired subject was kept in an isolation box throughout the experimental period.

Fifteen males and fifteen females were irradiated individually with the AFRRI-TRIGA reactor operated in the pulsed mode.[5] All received approximately the same dose of pulsed mixed gamma-neutron radiations except that five of each sex were head-shielded, five were trunk-shielded, and five were not shielded. Each subject

faced away from the reactor core with its center line about 80 cm from the vertical core center line. The methods of shielding have been described.[6]

Midline tissue doses to the head and chest of each monkey were calculated as follows. First, the midline tissue doses to the head and chest of a Lucite phantom were measured with miniature, tissue-equivalent ionization chambers. Simultaneously, the reactor power output was monitored with sulfur tablets. Factors were then derived to describe the relationship of sulfur-monitored neutron fluence from the reactor and midline tissue doses in the phantom.

During each animal exposure, the reactor power was again monitored with sulfur tablets; doses were calculated by using the appropriate factors. All animals received midline tissue doses of about 4500 rads to the unshielded parts of the body. The midline tissue dose behind the shield was less than 8 percent of the midline tissue dose to the same point without the shield in place.

The discrimination problem consisted of a circle and square presented simultaneously by illuminating two keys on a console in front of the monkey. The relative positions of the circle and square were switched in a random fashion. The correct response was to press the key illuminated with the square.

Each trial lasted 10 seconds. It was initiated by simultaneous illumination of a house light in the isolation box and the stimulus keys on the console. The monkey had 5 seconds to respond. For a correct response, both house light and stimuli extinguished for the duration of the 10 seconds. However, for an incorrect response or for no response, the stimuli extinguished, the house light remained on, a tone was initiated, and the animal received a brief electrical shock. Before irradiation,

each subject was trained to a proficiency of 90 or more correct responses per 100 presentations.

Each test period consisted of 100 trials presented at 10-second intervals and lasted 16.7 minutes. Each test period was followed by a rest period with the monkey in complete darkness. One test period started at the time of the reactor pulse and others started at 20, 40, 60, 80, and 100 minutes postexposure. The subject was then moved from the exposure room to another area for later testing. One test period was presented each time beginning at 3, 4, 5, 6, 7, and 8 hours postexposure. Testing was then continued at 2-hour intervals until death.

III. RESULTS

The term "performance decrement" is used to indicate fewer than 90 correct responses in a 100-trial test period. Among all subjects, incorrect responses were infrequent, i.e., the subject usually responded correctly or not at all. Results are presented in Tables I, II, and III.

Two-Hour Test Period. All of the unshielded subjects suffered performance decrement after irradiation and within this 2-hour test period. Eight of the ten monkeys failed to recover completely within 2 hours; in fact, five died within that time.

Among the head-shielded animals, three females and one male exhibited no early performance decrement. Only one female suffered any performance decrement beyond 20 minutes postexposure, and the decrement was very slight. All other performance decrements occurred very early, and the monkeys recovered to work at acceptable levels within 20 minutes postexposure.

Table I. Performance of Unshielded Monkeys after a 4500-rad Pulse of Mixed Gamma-Neutron Radiations

	Performance during first 2 hours after exposure						Survival time (hours)	Performance from 2 hours postirradiation until death		
	Time testing began relative to pulse (minutes)							Last response (hours after irradiation)	Number of test periods with 90 or more correct	Number of test periods with any correct
	0	20	40	60	80	100				
	Number of correct responses (100 possible)									
Males										
1	17	91	41	0	1	76	79	28.3	14	17
2	18	3	96	98	97	98	20.7	14.3	9	9
3	66	86	55	64	71	71	27	24.3	8	14
4	73	93	74	80	68	38	151	127	3	52
5	71	51	1	0	0	0	1.2	.7	--	--
Females										
6	17	0	0	0	0	0	.3	.1	--	--
7	31	99	0	0	0	0	1.9	.6	--	--
8	27	98	23	14	99	99	33	29.2	14	14
9	10	0	0	0	0	0	1	<.1	--	--
10	4	0	0	0	0	0	.3	<.1	--	--

Table II. Performance of Head-Shielded Monkeys after a 4500-rad Pulse of Mixed Gamma-Neutron Radiations

	Performance during first 2 hours after exposure						Survival time (hours)	Performance from 2 hours postirradiation until death		
	Time testing began relative to pulse (minutes)							Last response (hours after irradiation)	Number of test periods with 90 or more correct	Number of test periods with any correct
	0	20	40	60	80	100				
	Number of correct responses (100 possible)									
Males										
11	95	99	100	98	100	90	42	40.2	21	22
12	55	99	97	99	97	99	29.7	26.9	14	15
13	14	91	98	98	98	95	18	16	3	6
14	74	98	100	99	99	99	26.5	26	12	15
15	55	91	94	98	98	99	37	35.1	20	21
Females										
16	94	99	98	97	99	97	4.5	2	--	--
17	49	88	79	93	91	78	21.5	20	11	12
18	91	91	100	98	99	99	24.3	22	10	13
19	39	99	97	99	99	9.	18	17	10	11
20	93	99	100	99	99	92	20.5	18	10	10

Table III. Performance of Trunk-Shielded Monkeys after a 4500-rad Pulse of Mixed Gamma-Neutron Radiations

	Performance during first 2 hours after exposure						Survival time (hours)	Performance from 2 hours postirradiation until death		
	Time testing began relative to pulse (minutes)							Last response (hours after irradiation)	Number of test periods with 90 or more correct	Number of test periods with any correct
	0	20	40	60	80	100				
	Number of correct responses (100 possible)									
Males										
21	92	92	87	90	86	85	19	16	4*	10
22	98	98	86	96	96	96	78	51	17	28
23	97	99	99	100	100	98	36	30.5	16	17
24	13	0	96	100	100	100	35	32	18	18
25	13	97	77	21	100	100	49	43.5	22	24
Females										
26	45	67	88	96	96	98	38	28	13	16
27	42	75	65	82	20	6	50	32	15	19
28	98	76	50	43	40	16	41	22	3	8
29	76	98	100	100	100	100	21.5	21	11	12
30	40	96	94	94	90	91	29.5	20.3	11	12

* Shock mechanism became defective after 3 hours postexposure so monkey was not reinforced for poor performance. Condition was corrected about 7 hours postexposure.

Three of the trunk-shielded males showed slight or no performance decrement in the first 2 hours. Two females had early serious decrements but recovered fully within 20 minutes. Four subjects (two males and two females) suffered serious early performance decrements and required more than 20 minutes for recovery. One female had no decrement in the first 20 minutes but did show a continuous deterioration of performance through the remainder of the first 2 hours.

Overall Performance and Survival. Survival times of unshielded monkeys ranged from 17 minutes to 151 hours. One male and four females survived less than 2 hours. None died in the interval of 2 to 21 hours postirradiation.

The survival time of shielded monkeys was less variable than with unshielded animals. All shielded subjects lived more than 2 hours after irradiation but one

head-shielded female lived for only 4.5 hours. All other shielded subjects lived for at least 18 hours, and most lived for 20 hours or more. In both shielded groups, the mean survival time was slightly less for females than for males. The mean survival time for trunk-shielded subjects was slightly longer than for head-shielded subjects.

Except for the head-shielded female that died in 4.5 hours, all animals which survived the first 2 hours performed at acceptable levels for some time after the first 2 hours postexposure. This was true whether the monkey was unshielded, head-shielded, or trunk-shielded, and whether or not there was early performance decrement. Each monkey usually made its last response about 3 or 4 hours before death.

IV. DISCUSSION

The results indicate that, after irradiation under the conditions of this study, there is a high probability that early performance decrement will occur in unshielded monkeys. Either trunk shielding or head shielding will decrease the probability of early performance decrement. However, if a shielded animal does suffer an early performance decrement, the head-shielded monkey will recover sooner than the trunk-shielded monkey. Chapman and Young[1] found a similar response in monkeys that were required to perform a discrete avoidance task after a 6250-rad pulsed dose of fission spectrum radiations.

It was not possible to completely separate the importance of head and trunk effects. All of the monkeys did receive more than 350 rads to the shielded part of the body. That dose, about equal to the $LD_{50/60}$ for monkeys,[7] may have been

adequate (when combined with the higher dose to the unshielded body) to elicit some of the effects that are normally mediated through the structures that were shielded. Furthermore, the mixed gamma-neutron radiation could not be well collimated due to the large source dimensions and the short source-to-animal distance. Therefore, a dose gradient existed in the animals from the position corresponding to that of the dosimeter in the phantom to the midline position at the edge of the shield. Until these problems can be resolved, it is suggested that both head and trunk structures are implicated in the early performance decrement that occurs after irradiation of trained monkeys.

The results of the currently reported study indicate that, if an animal survives the first 2 hours postirradiation, it will recover to perform well for some time before death. Since both types of shielding decrease the probability of an early death, both increase the probability that the shielded subject can work several hours after irradiation, even though early transient incapacitation might occur. However, the unshielded subjects that escaped the early death worked and survived nearly as long as the shielded subjects.

Trunk shielding did extend survival time when compared to unshielded and head-shielded subjects ($P < 0.05$). However, the differences were small, especially if the unshielded animals that survived less than 2 hours are omitted. The extended survival of trunk-shielded animals contrasts to earlier results where head shielding extended the survival of beagles receiving pulsed mixed gamma-neutron radiations, but trunk shielding was not beneficial.[6] However, the beagles received doses of 19,000 rads or more compared to 4500 rads for the monkeys. This leads one to

speculate that, at relatively lower whole-body supralethal doses, the primary cause of death is damage to trunk structures, and survival time does not change rapidly with increased trunk doses. At higher doses, cephalic structures become relatively more important, and survival time decreases rapidly as the head dose is increased. However, since the monkeys were chaired and working, caution is required in comparing them to the dogs that were unrestrained (except for about 20 minutes during exposure) and not required to work.

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13. ABSTRACT

Fifteen male and fifteen female monkeys (Macaca mulatta) were trained by shock avoidance conditioning to work a visual discrimination problem. Each animal received a 4500-rad midline tissue dose of pulsed mixed gamma-neutron radiations; of each sex, five were head-shielded, five were trunk-shielded, and five were not shielded. The midline tissue dose behind the shield was less than 8 percent of the midline tissue dose to the same point without the shield in place. Postirradiation performance was evaluated. Early performance decrement occurred after irradiation in all unshielded monkeys. Either trunk shielding or head shielding decreased the probability of performance decrement. However, among the shielded monkeys that did suffer an early decrement, the head-shielded subjects recovered sooner than the trunk-shielded subjects.

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